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CURRENT AND C-V INSTABILITIES IN SiO_2 AT HIGH FIELDS

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ABSTRACT

Results have been obtained concerning the interrelation of current and C-V instabilities in MOS capacitors *subjected* to negative gate high field pulsing. Rising current transients and negative C-V shifts both show the formation of positive charge in the oxide. However, this charge appears to be situated close to the electrodes rather than in the bulk of the oxide and the temperature dependence of the rate of charge accumulation near the electrodes is different for the aluminum and silicon electrodes.

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In their studies of $Al-SiO_2$ - Si capacitors subjected to high field stressing many workers[1-4] have observed shifts to negative gate voltages in the capacitance vs voltage (C-V) curves corresponding to positive charge in the oxide. Rising current transients have also been observed and generally have been interpreted[1,3,5] as an increase in Fowler-Nordheim injection[6] due to holes remaining after impact ionization in the oxide.

There has been a tendency in the literature[1,3] to couple the two phenomena together and postulate that a bulk positive charge exists which influences both emission currents from the aluminum and C-V shifts in proportion to the distance of the charge from the respective interface.[3] There were, however, some facts which refuted this simple picture, notably:

1) Solomon[2,5] found that under suitable conditions the positive charge causing the current increase could reversibly be created and relaxed out of the insulator whereas in the same experiment the C-V shift continually increased.

2) DiMaria[7], using internal photoemission, has shown that the charge causing the C-V shift is confined near the Si - SiO_2 interface where it cannot influence the current injected from the gate.

The above facts prompted the present investigation and in this communication we shall show that two independent mechanisms exist for producing charge in the oxide at high fields; one producing charge which is trapped at the Si - SiO_2 interface (detected by C-V shifts) and the other at the $Al-SiO_2$ interface.

The samples consisted of 30 mil diameter 5000 Å thick Al dots evaporated from a resistance heated tungsten boat on a 715 Å thick SiO_2 film grown on a <100> 0.2 Ω-cm p-type silicon substrate. The oxide was grown at 1000° C in a dry oxygen ambient and a post-metallization anneal of 20 min in forming gas at 400° C was used. Mobile sodium concentrations measured using the temperature bias method were less than 5×10^{10} cm^{-2}.

A double pulse technique was used (see ref. 5 for more details) whereby the sample was prestressed at a relatively low field of 6.5 MV/cm (Al negative) stressed with a high field (>= 8MV/cm) pulse of the same polarity and then was returned to the low field condition. Currents were monitored at both high and low fields and C-V curves were taken before and after each pulse sequence. The experiment was repeated at room temperature, dry-ice and liquid nitrogen temperatures. The results are shown in Figs. 1 and 2. In Fig. 1 the cumulative flatband shift is plotted against cumulative pulsing time and in Fig. 2 the current I measured during a single pulse is shown as a function of time. The current is normalized to the extrapolated current at zero time, I_o. (The current cannot actually be measured at zero time due to transient effects.)

As expected, both negative C-V shifts and rising current transients were observed at high fields. The rates of current increase and C-V shift with time increased rapidly with applied field in a quasi-exponential manner. The current density is also a strong function of field according to the Fowler-Nordheim relation. However [illegible]ve two effects have even stronger field dependencies than the current density. This result, for the current, is in agreement with ref. 5. As is shown in the insert of Fig. 2, the current does not continue to increase at longer times, instead it saturates and eventually decreases slowly with time. This behaviour could be due to the combined effects of recombination and electron trapping.[8,9,10] In contrast to this, as seen in Fig. 1, the C-V shift increases monotonically with time.

Table 1 summarizes the temperature dependence of the voltage at which the C-V shifts or current increases became apparent. The threshold voltage for current increases drops rapidly as the temperature is lowered. The threshold voltage for the C-V shift is defined as the voltage at which a 0.2V shift is observed in the first ten second stressing pulse. This voltage does not depend strongly on temperature. It was impossible to measure the threshold for C-V shifts at liquid nitrogen temperature because the current runaway was strong enough to cause

breakdown in all the samples that were measured, before any trace of positive charging at the silicon interface was observed. The rate of C-V shift with time is seen to be temperature independent whereas the current increase phenomena is strongly enhanced at the lower temperatures. The differences are very striking when Figs. 1 and 2 are compared. The agreement in Fig. 1, in the rates of C-V shift at 300°K and 195°K is remarkable considering the steep voltage dependence of the effect. On the other hand, in agreement with ref. 5, there are orders of magnitude difference in the initial rates of current increase (1:65:5500 from Fig. 2) when going from room through dry ice to to liquid nitrogen temperatures.

The above results show differing temperature and time dependencies and offer strong proof that the C-V shifts and current increases are the result of independent processes. Indeed under suitable conditions, it is possible to get C-V shifts without current increases (at room temperature) or current increases without C-V shifts (at liquid nitrogen temperature). This supports the statements in the first paragraph where the charge causing the two effects is confined to the interface regions. In the case of radiation induced charge, photoemission work by Aitken et. al,[11] and hole transport measurements by Hughes,[12] similarly led to the conclusion that charge is trapped near the interfaces with little remaining in the bulk. It is possible that current increases could be obtained without accompanying C-V shifts if the current was highly localized (filimentary conduction). The reproducibility of the current increases from sample to sample argues against this. However, experiments are planned to resolve this point. It is important to note that charge localization near the electrodes only gives independence between C-V shifts and current increases for injection from the gate electrode. For the gate positive a close correlation between oxide current increases and C-V shifts should be observed. Such correlation has been observed in the past and further experiments are underway to confirm this.

The existence of two independent mechanisms for the formation of positive charge at the Al - SiO_2 and Si-SiO_2 interfaces under high field negative gate pulsing has been demonstrated. This opens a fruitful area of study as to the origin of these two effects and may enhance our understanding of the MOS system and possibly lead to improvements in field effect transistor technology.

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TABLE 1

THRESHOLD VOLTAGE

Temperature	77°K	195°K	300°K
Threshold voltage for current increase	52	56	60
Voltage for .2V CV shift in 10 seconds	Sample broke down	62	62

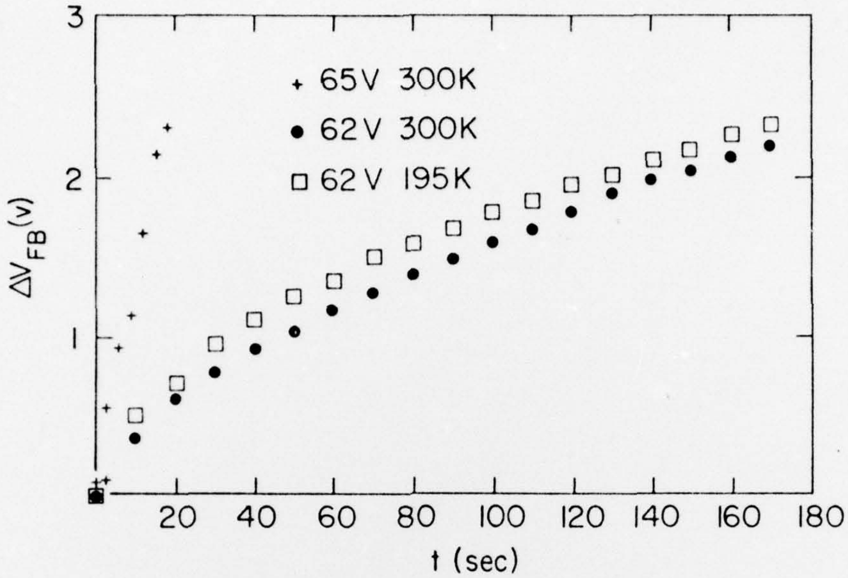

Fig. 1 Flatband voltage shift as a function of time for successive pulses.

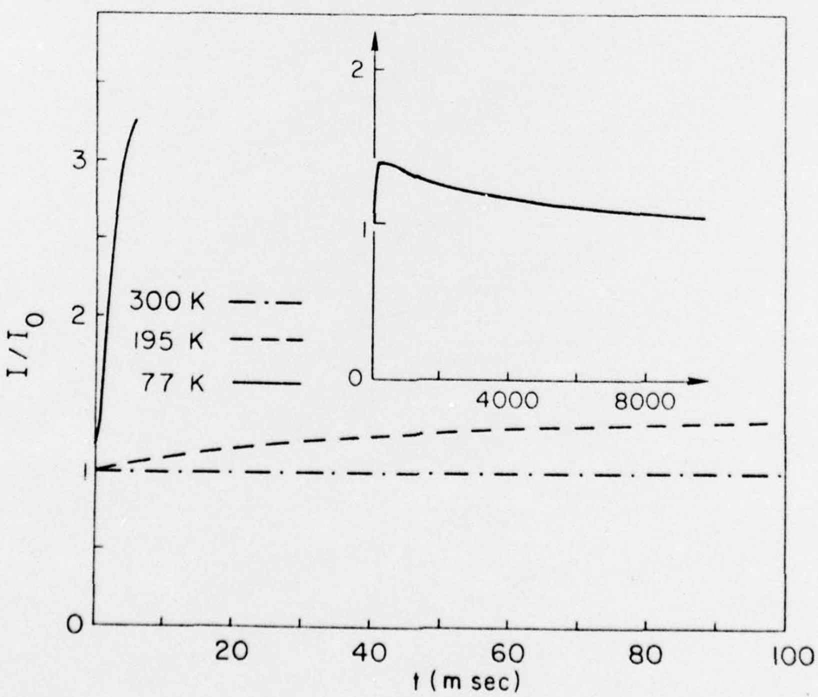

Fig. 2 Current vs time at 300°K, 195°K and 77°K for a -62V gate voltage applied at t=0. Insert shows the 195°K pulse on an expanded time scale. The time rates are in units of milliseconds in both the main figure and the insert.